IMPLEMENTATION OF STTCM AND OFDM SYSTEM IN DSP

by

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BONAFIDE CERTIFICATE

Certified that this project report entitled **"Implementation of STTCM and OFDM System in DSP"** is the bonafide work of **Mr.R.Narendiran** [Reg. no. 0710107061], **Mr.S.T.Pradeep Kumar** [Reg. no. 0710107067], **Mr.A.Ramesh** [Reg. no. 0710107078], and **Mr.D.Shiyam** [Reg. no. 0710107096], who carried out the research under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other project or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

Project Guide	15/4/11 **Head of the Department**
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19/4/11 **Internal Examiner**	**External Examiner**

ABSTRACT

In this project spectrally efficient and reliable transmission schemes is implemented which are used for high speed wireless communication link. The study of wireless communications with multiple transmission and reception antennas has been conducted expansively in the literature on Information Theory and communications. The application of multiple antennas in wireless systems can significantly improves the channel capacity over the single-antenna systems with the same requirements of power and bandwidth. Based on those results, many Communication schemes suitable for data transmission through multiple-antenna Wireless channels have been proposed, one such scheme space time coding. Its types are space time block coding (STBC) and space time trellis code modulation (STTC). Comparing to STBC, STTC is complex to design and it provides high coding gain and diversity gain and also immune to fading.

Recently, a worldwide convergence has occurred for the use of Orthogonal Frequency Division Multiplexing (OFDM) as an emerging technology for high data rates. In particular, many wireless standards have adopted the OFDM technology as a mean to increase dramatically future wireless communications. OFDM is a particular form of Multi-carrier transmission and is suited for frequency selective channels and high data rates. The combination of STTCM and OFDM serves the purpose. Our project is to implement these schemes in signal processors using the software code composer studio which converts the C file into a hex file for its implementation in the signal processor.

ACKNOWLEDGEMENT

First we would like to express my praise and gratitude to the Lord, who has showered his grace and blessing enabling me to complete this project in an excellent manner.

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INTRODUCTION

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INTRODUCTION

Communication is essential in every field. Technologies have improved and at present the era of wireless communication prevails. Spectrally efficient and reliable transmission schemes are used for high speed transmission data rate over wireless link. However reliable data communication is one of the major problems in modern wireless channels, since these channels should be able to tolerate the effects of signal fading channels and Inter Symbol Interference.

1.1 PROBLEM DEFINITION

The two main resources available for wireless communication are bandwidth and power. The efficiency in wireless communication relies on the efficient use of the bandwidth as it is a costly resource. As the number of customers is increasing every day, bandwidth is becoming extinct. So as to make efficient use of bandwidth, modulation schemes which require less bandwidth should be developed. Data rate is also a major issue in wireless communication. The wireless communication data rates are very low because of the fading effects in the channel. This issue is to be addressed and a new modulation technique should be developed which provides high data rate for wireless communication.

1.2. LITERATURE SURVEY

The study of wireless communications with multiple transmits and Receive antennas has been conducted expansively in the literature on information Theory and communications. The application of multiple antennas in wireless systems can significantly improves the channel capacity over the single-antenna systems with the same requirements of power and bandwidth. Based on those results, many communication schemes suitable for data transmission through multiple-antenna Wireless channels have been proposed, including Bell Labs Layered Space–Time code, Space time trellis codes, space–time block codes from orthogonal designs, and unitary space–time codes and concatenated space time coding which has the disadvantage of complex decoding structure due to the use of interleaver and among many others.

In recent years a range of transmitting diversity techniques has been proposed in order to provide diversity gain for wireless communication. Only a few years after its invention, Space-Time Code (STC) has also been introduced to employment in the third generation (3G) mobile communication standards, especially after Alamouti proposed Space-Time Block Code (STBC). STBC can achieve maximum possible diversity advantage with simple decoding algorithm. It is very attractive because of their simplicity. However, the coding gain provided by Space-Time Block Codes is very limited and non-fill rate Space-Time Block Codes can introduce bandwidth expansion. By comparison, Space-Time Trellis Code (STTC) is obtained by a joint design of error control coding, modulation, transmitting and receiving diversity to combat the effects of fading. STTC can simultaneously offer substantial coding gain, spectral efficiency and diversity improvement on flat fading channels.

1.3. OVERVIEW OF THE PROJECT

The space time trellis code modulation (STTCM) technique along with the multiplexing method of orthogonal frequency division multiplexing facilitates a bandwidth efficient modulation scheme for wireless communication.

Space-time trellis coded modulation (ST-TCM) has emerged as a promising method for enhancing performance of a digital communication system in wireless fading channels The STTCM scheme has resistance over fading due to the diversity in the signal transmission. In this type of modulation scheme, two or more transmission antennas are used for signal transmission which provides space diversity to overcome the effect of fading.

At the same time, the Orthogonal Frequency Division Multiplexing (OFDM) technique can transform a fading channel into parallel correlated flat-fading channels. Hence, it is natural to combine STTC with the OFDM system to achieve more improved communication performance. Orthogonal Frequency Division Multiplexing (OFDM) uses the orthogonality feature for bandwidth efficiency. In OFDM, the frequencies of the carriers are orthogonal to each other due to which more information can be communicated with limited bandwidth. Moreover OFDM has the advantage of overcoming the effects of Inter symbol Interference and provides high data rates for communication.

1.4. IMPLEMENTATION

In this project, we are implementing the above mentioned bandwidth efficient modulation technique in digital signal processor using C language. When compared to any other processors the digital signal processors are more easy for implementing the operation that are to be carried out for the processing and the conversion of the ordinary binary signals to the necessary modulation scheme. DSP provides better control of accuracy requirements. Digital signals can be easily stored without deterioration. More sophisticated signal processing algorithms can be implemented. For implementation of the program in DSP the code composer studio software is used the code composer studio has the ability to convert the C file to hex file that is to be implemented in the digital signal processor. Code composer studio is an integrated development environment which is used for programming the DSP of Texas instrument.

CCS has an efficient compiler which saves time by programming in C. It includes integrated code generation tools which support features like graphically configuring build options background build etc. The code composer studio includes the real time operating system called DSP/BIOS. DSP/BIOS is a real time operating system created and offered by Texas Instruments (TI) for use in a wide range of their embedded processors. So for efficient use of the available bandwidth for the maximum number of users along with high data capacity this a method of implementation of a modulation scheme for wireless communication.

CHAPTER 2

SPACE TIME TRELLIS CODE MODULATION

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2.1. TRELLIS CODED MODULATION (TCM)

TCM uses many diverse concepts for signal processing. It is a combination of coding and modulation for digital transmission over band limited channels; hence the name trellis coded modulation, where the trellis stands for the use of the trellis codes (also known as convolutional code). Ungerboeck (1976) showed that for band limited channels substantial coding gains could be achieved by convolutional coding of signal levels (rather than coding of binary source levels). TCM is a complex concept due to the non linear nature of its performance. It uses the idea from modulation and coding as well as dynamic programming, lattice structures and matrix math. A Convolutional code that has optimum performance when used independently may not be optimum in TCM. Trellis coding is a forward –error correction scheme where coding and modulation are treated as a combined entry rather than two separate operations. It has better immunity to channel impairments with non redundant coding, an advantage that is gained without an increase in bandwidth requirements. In quantitative terms, trellis coding provides an effective coding gain of 4 db compared to 16-QAM. Coding gain expresses how much signal energy per data is needed by the uncoded modem for the same level of noise performance. TCM scheme employ redundant non binary modulation in combination with a finite state encoder which governs the selection of modulation signals to generate coded signal sequences.

2.1. CONCEPT OF TRELLIS CODED MODULATION

Trellis Code Modulation is one of the coded modulation techniques used in digital communications. It combines the choice of a modulation scheme with that of a convolutional code together for the purpose of gaining noise immunity over uncoded transmission without expanding the signal bandwidth or increasing the transmitted power. Trellis Coded Modulation, or TCM, was invented as a method to improve the reliability of a digital transmission system without bandwidth expansion or reduction of data rate. Normal channel codes such as block and convolutional codes improve the performances of the communication system by expanding the bandwidth. The Euclidean distance between the transmitted coded waveforms would be increased by the use of coding, but at the price of increasing the bandwidth. Trellis coded modulation is a coded modulation scheme that can increase the noise immunity and simultaneously do not increase the bandwidth. Therefore, Trellis Coded Modulation is suitable for band-limited channels.

Trellis Coded Modulation is an enhancement of QAM, which adds a large number of redundant bits to each Symbol, a technique known as Forward Correction. The result is that a given Symbol has more invalid than valid bit combinations, and this means that bit errors have a higher probability of being detected at the transmission level. In TCM, the receiver uses the extra data from the previous Symbol to check the accuracy of the current Symbol. Trellis Coded Modulation (TCM) is used widely in high-speed voice-band modems. Without coding, high-speed modems achieved data rate up to 9600 bits/sec with $M = 16$ QAM signal constellation. The added coding gain provided by Trellis Coded

Modulation has made it possible to increase the speed of the transmission by at least a factor of 2.

2.2. SPACE TIME CODES

A space–time code (STC) is a method employed to improve the reliability of data transmission in wireless communication systems using multiple transmit antennas. STCs rely on transmitting multiple, redundant copies of a data stream to the receiver in the hope that at least some of them may survive the physical path between transmission and reception in a good enough state to allow reliable decoding.

Space time codes may be split into two main types:

- Space–time trellis codes (STTCs) distribute a trellis code over multiple antennas and multiple time-slots and provide both coding gain and diversity gain.
- Space–time block codes (STBCs) act on a block of data at once (similarly to block codes) and provide only diversity gain, but are much less complex in implementation terms than STTCs.

2.2.1. SPACE–TIME BLOCK CODING

Space–time block coding is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas with a symbol duration delay [3] and to exploit the various received versions of the data to improve the reliability of data-transfer. The fact that the transmitted signal must traverse a potentially difficult environment with scattering, reflection, refraction and so on and may then be further corrupted by thermal in the receiver means that some of the received copies of the data will be better than others. This redundancy results in a higher chance of being able to use one or more of the received copies to correctly decode the received signal. In fact, coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible. STBC is a transmit diversity technique capable of creating diversity at the receiver to improve the performance of communications systems. STBC utilizes N transmit antennas separated far apart to ensure independent fades. At a given symbol period, N signals are transmitted simultaneously from N antennas. The signal transmitted from each antenna has a unique structure that allows the signal to be combined and recovered at the receiver.

The advantages are Space-time block coding utilizes multiple antennas to create spatial diversity; this allows a system to have better performance in a fading environment. Good performance with minimal decoding complexity. Space time block codes can achieve maximum diversity gain equivalent to space-time trellis codes. The disadvantages are block codes does not have as much coding gain as space-time trellis codes. Block codes cannot always achieve the maximum data rates allowed by the general theory of space-time codes.

2.2.2. SPACE TIME TRELLIS CODE

Space-time coding (STC) schemes combine the channel code design and the use of multiple transmit and receive antennas. The encoded data is split into

N_T streams that are simultaneously transmitted using N_T transmit antennas. The received signal is a linear superposition of these simultaneously transmitted symbols corrupted by noise and fading. Space-time decoding algorithms as well as channel estimation techniques are incorporated at the receiver in order to achieve diversity advantage and coding gain. Space-Time Trellis Codes (STTC) was originally proposed by Tarokh et al[8] from AT&T research labs, which combine the design of channel coding with the symbol mapping onto multiple transmit antennas. These codes are designed to obtain maximum diversity gain and provide the best tradeoff between constellation size, data rate, trellis complexity and diversity advantage [9]. The encoder is composed of N_T different generator polynomials to determine the simultaneously transmitted symbols. The receiver is based on channel estimation of the fade coefficients and Maximum Likelihood Sequence Estimation (MLSE) decoder, which computes the lowest Euclidean distance metric to extract the most likely transmitted sequence. Literature has shown that STTC achieve greater coding gain than Space-Time Block Codes (STBC) [14], and are shown to outperform layered space-time codes. Space-Time trellis codes can be considered to function in a similar manner to a convolutional encoder, and the connection weights and output symbols form part of an M-ary alphabet. STTC is a transmit diversity technique that combines space diversity and coding gain to improve the performance of communication systems. STTC utilizes N transmit antennas separated far apart to ensure independent channels. At a given symbol period, N signals are transmitted simultaneously from N antennas. The signal transmitted from each antenna has a unique structure with inherent error-correction capability to allow signal to be recovered and corrected at the receiver.

2.2.3. SPACE TIME TRELLIS ENCODER

The space time trellis encoder structure consists of two antennas which transmit the signals simultaneously at two different times. The two antennas are provided with space diversity to overcome the effect of fading in the channel.

2.2.4. ALGORITHM FOR STTCM ENCODER

- Number of input bits and the input sequence are obtained from the user.
- First bit of the input is given to antenna 1 and next is given to antenna 2, repeated till last bit. This done by using a loop.
- The initial delay bits are assigned as zero.
- The other delay bits are assigned using a loop.
- Values of the weights are obtained from the user.
- The message bits are encoded using the following formula,
  - Transmitted signal by Antenna 1:

$$x_{k,1} = 0.d_{k,1} + 0.d_{k,2} + 1.d_{k-1,1} + 2.d_{k-1,2}$$

  - Formula used in Antenna 2:

$$x_{k,2} = 1.d_{k,1} + 2.d_{k,2} + 0.d_{k-1,1} + 0.d_{k-1,2}$$

- To calculate the encoded bits, n number of loops is used, where n, denotes number of antennas.

According to the shift register shown in above figure, legitimate subsequent state can be determined, which results in transmitting various symbols $x_{k,1}$ and $x_{k,2}$ depending on a particular state of the shift register, so that state diagram for the encoder can be constructed. The 4state constellation points are shown in the figure 2.2, while the corresponding state diagram of 4state 4PSK space time trellis code is shown in figure 2.3.

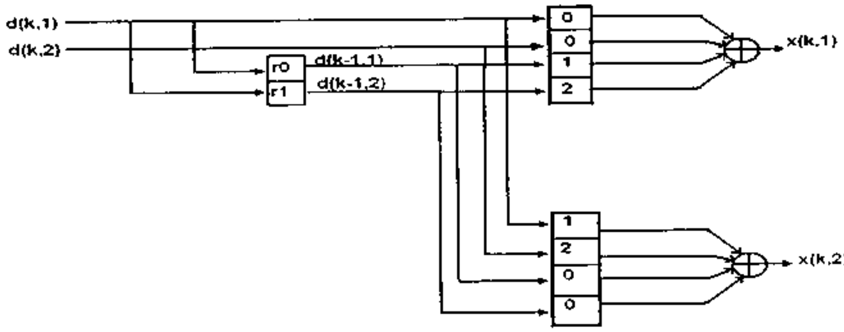

FIG.2.1. SPACE TIME TRELLIS ENCODER

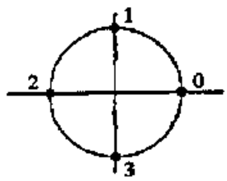

FIG.2.2. 4STATE CONSTELLATION POINTS

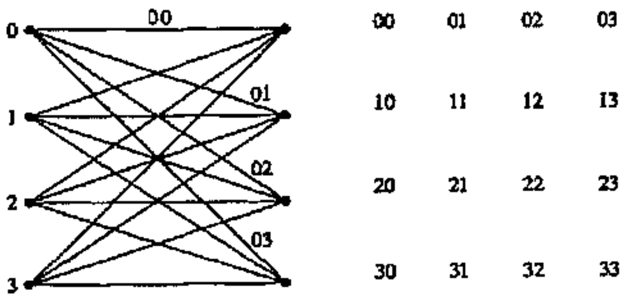

FIG.2.3. 4 STATE 4PSK SPACE TIME TRELLIS CODE

2.2.5. SPACE TIME TRELLIS DECODER

From the transmitter two symbols are transmitted such as x_1 and x_2. These multiple copies of the data are used by the receiver to reconstruct the actual transmitted data. The received signals at the receiver are $y_1=h_{11}x_1+h_{12}x_2+n_1$ and $y_2=h_{21}x_1+h_{22}x_2+n_2$, where n_1 and n_2 are noises added in the channel. $h_{11},h_{12},h_{21},h_{22}$ are the corresponding time domain channel transfer factors. The decoding method used is viterbi decoder. This first finds the branch metric associated with every transition in the decoding trellis diagram, which is identical to the state diagram shown in figure 2.3. For each trellis two estimated transmit symbols namely $\hat{x}_1$ and $\hat{x}_2$ for which the branch metrics are calculated.

2.2.6. ALGORITHM OF STTCM DECODER

- Trellis structure is formed by obtaining the values from the user.
- Present state is assigned to zero.
- Values of the weights are obtained from the user.
- Y is calculated for all the encoded bits using the following formula

$$y_1 = h_{11}x_1 + h_{12}x_2 + n_1$$

$$y_2 = h_{21}x_1 + h_{22}x_2 + n_1$$

- Inside the loop all the variables which is assigned to store the values of the branch matrix is assigned to zero.
- Switch case is used to function based on the value of the present state.
- Branch matrix is calculated from the initial state and the state with minimum branch matrix is assigned as next state.
- Branch matrix is calculated till the last encoded bit and the data is decoded using trellis structure.

$$BM = | y_1 - h_{11}\tilde{x}_1 - h_{12}\tilde{x}_2 + y_2 - h_{21}\tilde{x}_1 - h_{22}\tilde{x}_2 |^2$$

- The decoded data will be in the decimal form, which will be converted to binary values.

2.2.7. VITERBI DECODER

In 1967, Viterbi developed the Viterbi Algorithm (VA) as a method to decode Convolutional codes.The Viterbi algorithm is a dynamic programming algorithm for finding the most likely sequence of hidden states – called the Viterbi path – that results in a sequence of observed events, especially in the context of Markov information sources, and more generally, hidden Markov models. The forward algorithm is a closely related algorithm for computing the probability of a sequence of observed events. These algorithms belong to the realm of information theory.

The algorithm makes a number of assumptions.

- First, both the observed events and hidden events must be in a sequence. This sequence often corresponds to time.
- Second, these two sequences need to be aligned, and an instance of an observed event needs to correspond to exactly one instance of a hidden event.
- Third, computing the most likely hidden sequence up to a certain point t must depend only on the observed event at point t, and the most likely sequence at point t − 1.

The VA uses the trellis diagram to decode an input sequence, as shown in Figure below. The VA, which uses a hard decision format, is exhibited in Figure below.

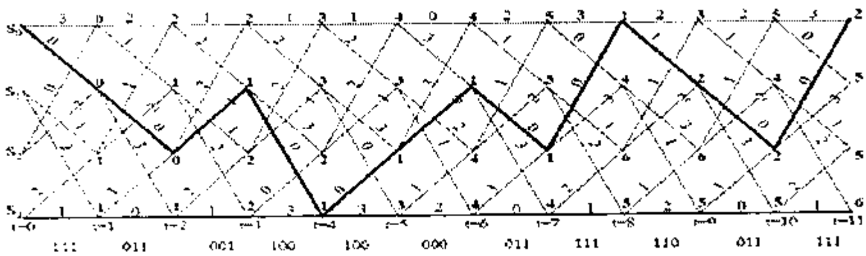

FIG.2.4. VITERBI-TRACE BACK

A node is assigned to each state for each time stage. The transition between two states is represented by a branch, which is assigned a weight, referred to as a branch metric (BM). The BM is calculated by using the formula

$$BM = | y_1 - h_{11}\tilde{x}_1 - h_{12}\tilde{x}_2 + y_2 - h_{21}\tilde{x}_1 - h_{22}\tilde{x}_2 |^2$$

The BM is a measure of the likelihood of the transition, given the noisy observations. The BMs that are accumulated along a path form a path metric (PM). For the two branches entering the same state, the branch with the smaller PM survives, and the other one is discarded. Then method used to extract the decoded bits is the trace back (TB) method.

A Viterbi decoder uses the Viterbi algorithm for decoding a bit stream that has been encoded using forward error correction based on a Convolutional code. The steps involved in Viterbi decoder is shown in flow chart below.

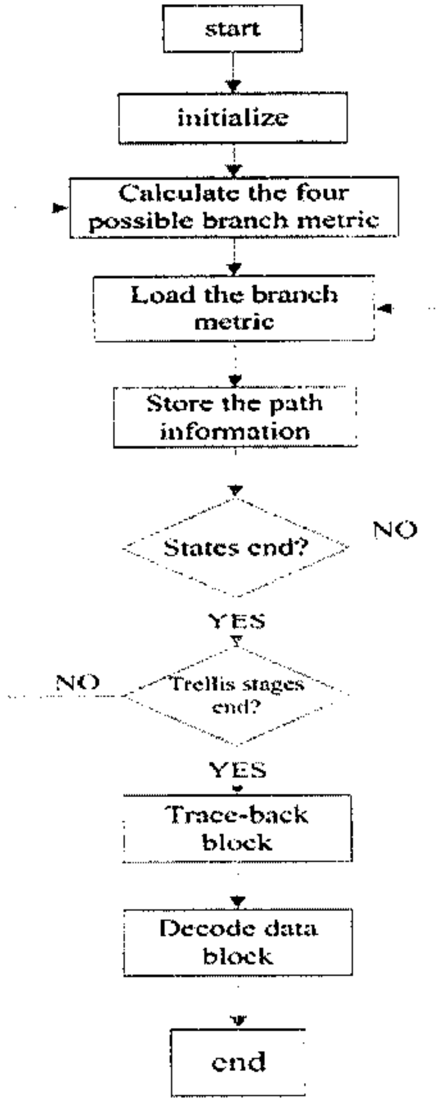

FIG.2.5. FLOW CHART FOR VITERBI DECODER

The advantages of viterbi decoder are reduction in computational complexity by using the recursion - this argument is exactly analogous to that used in justifying the forward algorithm. It has fixed decoding time and high speed of operation.

CHAPTER 3

ORTHOGONALFREQUENCY DIVISION MULTIPLEXING

CHAPTER 3

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

3.1. MULTIPLEXING

Multiplexing is sending multiple signals or streams of information on a carrier at the same time in the form of a single, complex signal and then recovering the separate signals at the receiving end. The multiplexed signal is transmitted over a communication channel, which may be a physical transmission medium. The multiplexing divides the capacity of the low-level communication channel into several higher-level logical channels, one for each message signal to be transferred. Demultiplexing, can extract the original channels on the receiver side. Multiplexing is a efficient method for communication which requires less bandwidth for communication of large amount of information and multiplexing also allows transmission of variable bit rates of data streams.

3.1.1. TYPES OF MULTIPLEXING

Multiplexing techniques may be divided into several types

3.1.2. FREQUENCY-DIVISION MULTIPLEXING (FDM)

This form on multiplexing is an analog technique that uses a process of dividing the bandwidth into a series of sub channels that will accommodate the transmissions by allowing them to flow forward in a parallel fashion. In FDM signals of different frequencies are transmitted at same time. One of FDM's most common applications is cable television. Only one cable reaches a customer's home but the service provider can send multiple television channels or signals simultaneously over that cable to all subscribers. Receivers must tune to the appropriate frequency (channel) to access the desired signal. The advantages of FDM are, FDM is not sensitive to propagation delays. Channel equalization techniques needed for FDM systems are not as complex as those for TDM systems.

A variant technology, called wavelength-division multiplexing (WDM) is used in optical communications

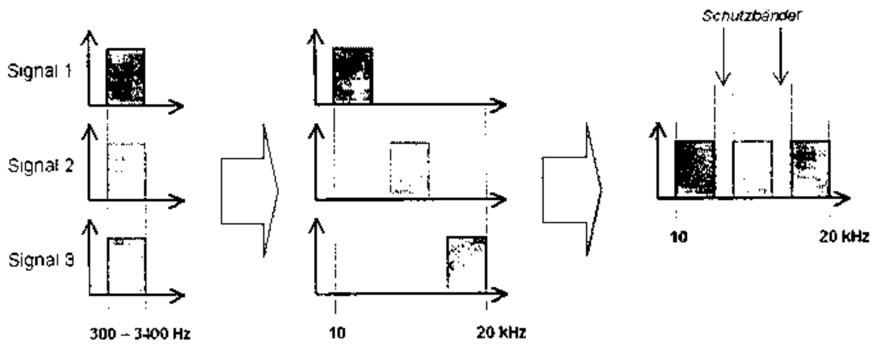

FIG.3.1. FREQUENCY-DIVISION MULTIPLEXING (FDM)

3.1.3. TIME-DIVISION MULTIPLEXING (TDM)

In digital transmission, signals are commonly multiplexed using time-division multiplexing (TDM), in which the multiple signals are carried over the same channel in alternating time slots. In TDM signals of same frequency are transmitted in different time slots. These alternating slots are still carried within a common channel, within the available bandwidth.

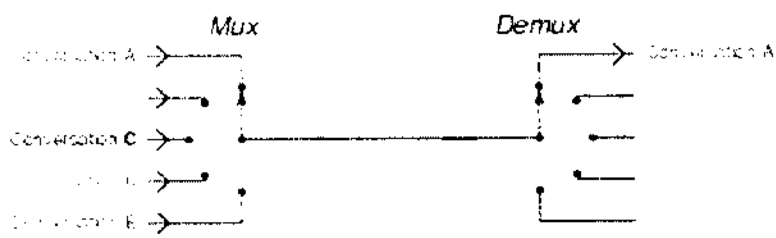

FIG.3.2. TIME-DIVISION MULTIPLEXING (TDM).

3.1.4. CODE DIVISION MULTIPLEXING (CDM)

Code division multiplexing (CDM) is a technique in which each channel transmits its bits as a coded channel-specific sequence of pulses. This coded transmission typically is accomplished by transmitting a unique time-dependent series of short pulses, which are placed within chip times within the larger bit time. All channels, each with a different code, can be transmitted on the same fiber and asynchronously demultiplexed. Code Division Multiplexing techniques are used as an access technology, namely Code Division Multiple Access (CDMA), in Universal Mobile Telecommunications System (UMTS) standard for the third generation (3G) mobile communication identified by the ITU. Another important application of the CDMA is the Global Positioning System (GPS).

3.2. OFDM

OFDM is a special case of frequency division multiplexing (FDM). If the FDM system had been able to use a set of subcarriers that were orthogonal to each other, a higher level of spectral efficiency could have been achieved. The guard bands that were necessary to allow individual demodulation of subcarriers in an FDM system would no longer be necessary. The use of orthogonal subcarriers would allow the subcarriers spectra to overlap, thus increasing the spectral efficiency. As long as orthogonality is maintained, it is still possible to recover the individual subcarriers signals despite their overlapping spectrums. If the dot product of two deterministic signals is equal to zero, these signals are said to be orthogonal to each other. Orthogonality can also be viewed from the standpoint of stochastic processes. If two random processes are uncorrelated, then they are orthogonal. Given the random nature of signals in a communications system, this probabilistic view of orthogonality provides an intuitive understanding of the implications of orthogonality in OFDM. Later in this article, we will discuss how OFDM is implemented in practice using the discrete Fourier transform (DFT). Recall from signals and systems theory that the sinusoids of the DFT form an orthogonal basis set, and a signal in the vector space of the DFT can be represented as a linear combination of the orthogonal sinusoids [13]. One view of the DFT is that the transform essentially correlates its input signal with each of the sinusoidal basis functions. If the input signal has some energy at a certain frequency, there will be a peak in the correlation of the input signal and the basis sinusoid that is at that corresponding frequency. This transform is used at the OFDM transmitter to map an input signal onto a set of orthogonal subcarriers, i.e., the orthogonal basis functions of the DFT. Similarly, the transform is used again at the OFDM receiver to process the received subcarriers. The signals from the subcarriers are then combined to form an estimate of the source signal from the transmitter. The orthogonal and uncorrelated nature of the subcarriers is exploited in OFDM with powerful results. Since the basis functions of the DFT are uncorrelated, the correlation performed in the DFT for a given subcarrier only sees energy for that corresponding subcarrier. The energy from other subcarriers does not contribute because it is uncorrelated. This separation of signal energy is the reason that the OFDM subcarriers' spectrums can overlap without causing interference.

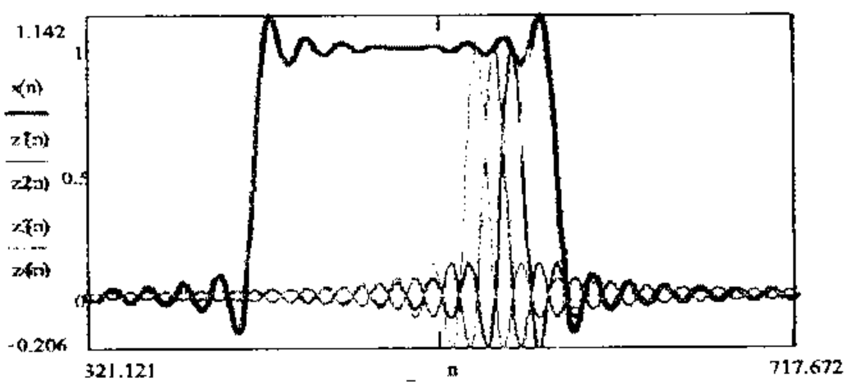

FIG.3.3. FREQUENCY REPRESENTATION OF OFDM

3.2.1. ORTHOGONALITY

The sub-carrier frequencies are chosen so that they are orthogonal to each other. This means that cross-talk between the sub-carriers is not possible and hence inter-carrier guard bands are not required. The Orthogonality allows:

- Simultaneous transmission on numerous sub-carriers in a tight frequency band without interference from each other
- High spectral efficiency, near the Nyquist rate
- Simpler transmitter and receiver design
- Efficient modulator and demodulator implementation using the FFT algorithm

However, in order to maintain Orthogonality, very accurate frequency synchronization is required between the receiver and transmitter. If the frequency deviates, the sub-carriers would not remain orthogonal causing inter-carrier interference. Figure 3.1 shows the six sub-carriers which are orthogonal to each other.

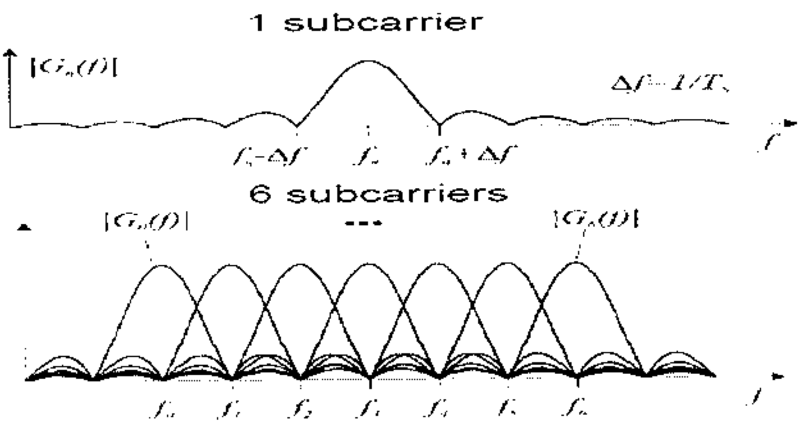

FIG.3.4. ORTHOGONALITY OF SUB CARRIERS

3.3. PRINCIPLES OF OFDM

OFDM is a block transmission technique. In the baseband, complex-valued data symbols modulate a large number of tightly grouped carrier waveforms. The transmitted OFDM signal multiplexes several low-rate data streams-each data stream is associated with a given subcarrier.

The main advantage of this concept is in a radio environment, each of that data streams experiences an almost flat fading channel. In slowly fading channels, the ISI and ICI within an OFDM symbol can be avoided with a small loss of transmission energy using the concept of cyclic prefix.

3.4. OFDM MODEL USED

The OFDM system model is shown in Figure below. A brief description of the model is provided below.

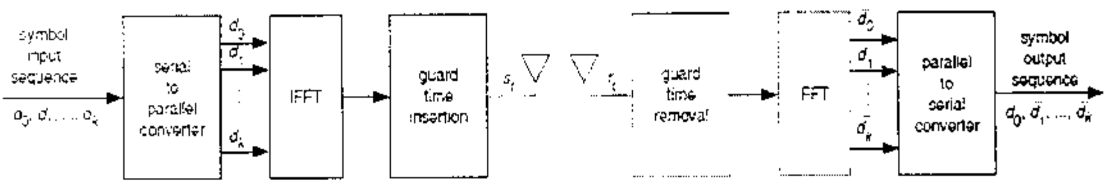

FIG.3.5. OFDM MODEL USED

3.4.1. SERIAL TO PARALLEL CONVERSION

The input serial data stream is formatted into the word size required for transmission, e.g. 2 bits/word for QPSK, and shifted into a parallel format. The data is then transmitted in parallel by assigning each data word to one carrier in the transmission. In an OFDM system, each channel can be broken into various sub-carriers. The use of sub-carriers makes optimal use out of the frequency spectrum but also requires additional processing by the transmitter and receiver.

This additional processing is necessary to convert a serial bit stream into several parallel bit streams to be divided among the individual carriers. Once the bit stream has been divided among the individual sub-carriers, each sub-carrier is modulated as if it was an individual channel before all channels are combined back together and transmitted as a whole [13]. The receiver performs the reverse process to divide the incoming signal into appropriate sub-carriers and then demodulating these individually before reconstructing the original bit stream.

3.4.2 MODULATION OF DATA

The data to be transmitted on each carrier is then differential encoded with previous symbols, then mapped into a Phase Shift Keying (PSK) format. Since differential encoding requires an initial phase reference an extra symbol is added at the start for this purpose. The data on each symbol is then mapped to a phase angle based on the modulation method. For example, for QPSK the phase angles used are 0, 90, 180, and 270 degrees. The use of phase shift keying produces a constant amplitude signal and was chosen for its simplicity and to reduce problems with amplitude fluctuations due to fading.

3.4.3 INVERSE FOURIER TRANSFORM

After the required spectrum is worked out, an inverse Fourier Transform is used to find the corresponding time waveform. The guard period is then added to the start of each symbol. The modulation of data into a complex waveform occurs at the Inverse Fast Fourier Transform (IFFT) stage of the transmitter. Here, the modulation scheme can be chosen completely independently of the specific channel being used and can be chosen based on the channel requirements. In fact, it is possible for each individual sub-carrier to use a different modulation scheme. The role of the IFFT is to modulate each sub-channel onto the appropriate carrier.

3.4.4. CYCLIC PREFIX

The cyclic prefix is transmitted during the guard interval and it consists of the end of the OFDM symbol copied into the guard interval. The cyclic prefix is transmitted followed by the OFDM symbol. Cyclic prefix Insertion is shown in below Figure .

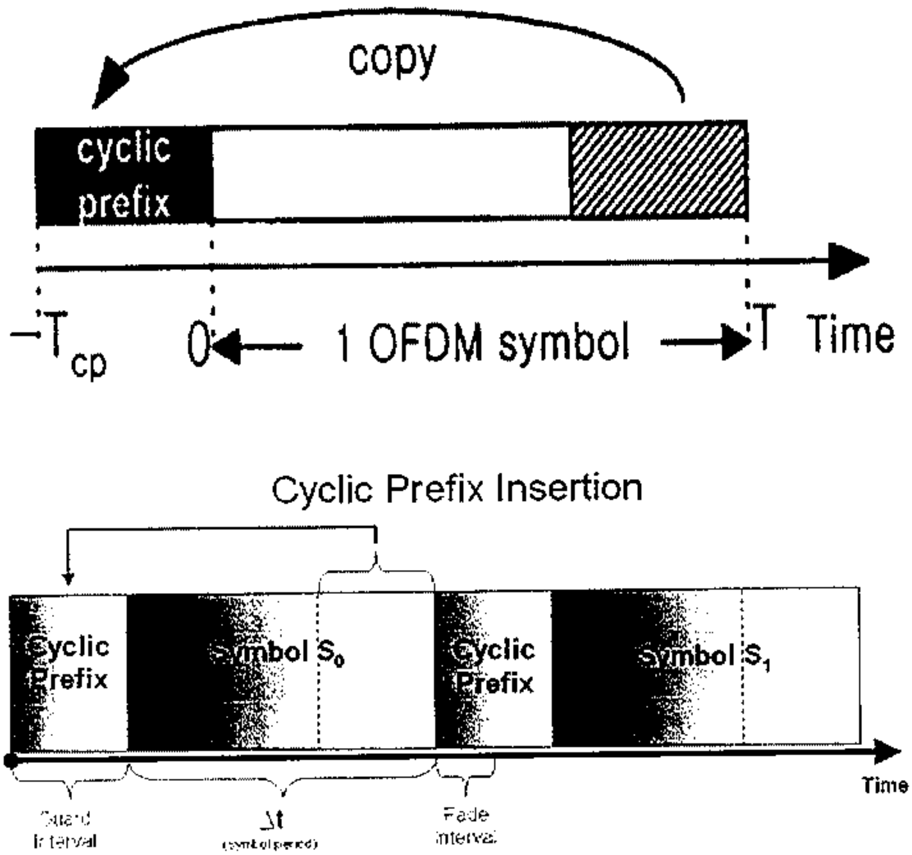

FIG.3.6. INSERTION OF CYCLIC PREFIX

The reason for the cyclic prefix being a copy of the OFDM symbol's tail is so that the receiver will integrate over an integer number of sinusoidal cycles for each of the multi-path components when it performs OFDM demodulation with the FFT. The disadvantage of using a cyclic extension is a less available bandwidth for the real data transmission. In most environments, the length of the Guard interval is equal to a quarter symbol duration. This is a stable compromise between the less bandwidth efficiency and the better performance due to interferences.

Because wireless communications systems are susceptible to multi-path channel reflections, a cyclic prefix is added to reduce ISI. A cyclic prefix is a repetition of the first section of a symbol that is appended to the end of the symbol. In addition, it is important because it enables multi-path representations of the original signal to fade so that they do not interfere with the subsequent symbol.

3.4.5. GUARD INTERVAL

OFDM transmits a number of low-rate streams in parallel instead of a single high-rate stream. Lower symbol rate modulation means the symbol duration is comparatively longer and it is feasible to insert a guard interval between OFDM symbols.

The presence of this guard interval makes the system resilient to multipath components and helps to eliminate inter-symbol interference. The guard interval also eliminates the need for pulse-shaping filter and reduces the sensitivity to time synchronization problems.

The guard period used was made up of two sections. Half of the guard period time is a zero amplitude transmission. The other half of the guard period is a cyclic extension of the symbol to be transmitted.

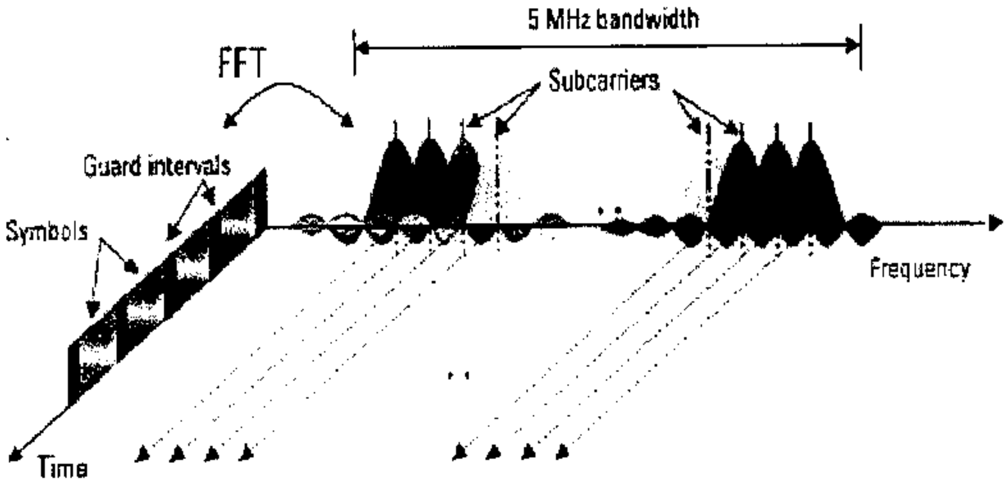

FIG.3.7. GUARD INTERVAL BETWEEN OFDM SYMBOLS

This was to allow for symbol timing to be easily recovered by envelope detection. However it was found that it was not required in any of the simulations as the timing could be accurately determined position of the samples.

After the guard has been added, the symbols are then converted back to a serial time waveform. This is then the base band signal for the OFDM transmission.

3.4.6 CHANNEL

A channel model is then applied to the transmitted signal. The model allows for the signal to noise ratio, multipath, and peak power clipping to be controlled. The signal to noise ratio is set by adding a known amount of white noise to the transmitted signal. Multipath delay spread then added by simulating the delay spread using an FIR filter. The length of the FIR filter represents the maximum delay spread, while the coefficient amplitude represents the reflected signal magnitude.

3.4.7 RECEIVER

The receiver basically does the reverse operation to the transmitter. The guard period is removed. The FFT of each symbol is then taken to find the original transmitted spectrum. The phase angle of each transmission carrier is then evaluated and converted back to the data word by demodulating the received phase. The data words are then combined back to the same word size as the original data.

3.5. OFDM ADVANTAGES

The combination of high data capacity, high spectral efficiency, and its resilience to interference as a result of multi-path effects means that it is ideal for the high data applications that are becoming a common factor in today's communications scene. OFDM can easily adapt to severe channel conditions without the need for complex channel equalization algorithms being employed It is robust when combating narrow-band co-channel interference. As only some of the channels will be affected, not all data is lost and error coding can combat this. Inter symbol interference, [13] ISI is less of a problem with OFDM because low data rates are carried by each carrier. OFDM Provides high levels of spectral efficiency. Relatively insensitive to timing errors Allows single frequency networks to be used - particularly important for broadcasters where this facility gives a significant improvement in spectral usage. Orthogonal frequency division multiplexing is commonly implemented in many emerging communications protocols because it provides several advantages over the traditional FDM approach to communications channels. More specifically, OFDM systems allow for greater spectral efficiency reduced intersymbol interference (ISI), and resilience to multi-path distortion.

- OFDM is spectrally efficient
  - IFFT/FFT operation ensures that sub-carriers do not interfere with each other
- OFDM has an inherent robustness against narrowband interference
  - Narrowband interference will affect at most a couple of sub channels
  - Information from the affected sub channels can be erased and recovered via the forward error correction codes
- Equalization is very simple compared to Single-Carrier systems
- OFDM has excellent robustness in multi-path environments
  - Cyclic prefix preserves orthogonality between sub-carriers
  - Cyclic prefix allows the receiver to capture multi-path energy more efficiently
- Ability to comply with world-wide regulations:
  - Bands and tones can be dynamically turned on/off to comply with changing regulations
- Coexistence with current and future systems:
  - Bands and tones can be dynamically turned on/off for enhanced coexistence with the other devices.

3.5.1. SPECTRAL EFFICIENCY

In a traditional FDM system, each channel is spaced by about 25% of the channel width. This is done to ensure that adjacent channels do not interfere. This is illustrated in the diagram below, which shows the guard bands between individual channels.

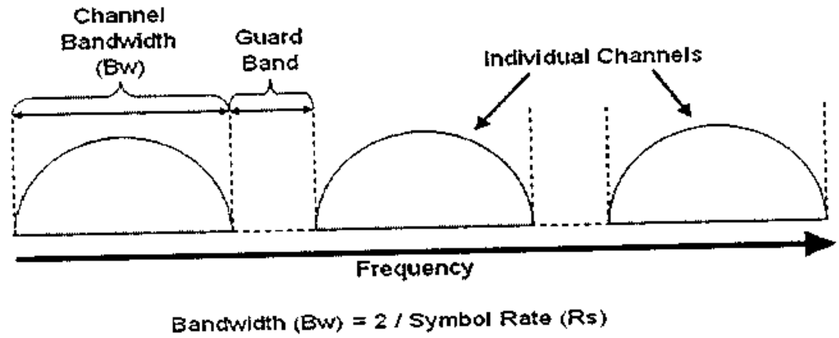

FIG.3.8. GUARD BAND SPECTRUM IN FDM

Because of the requirement for guard bands, it is required to the symbol rate to allow for guard bands to exist. In general, the allowed channel bandwidth (BW) is 2/Rs. As a result of this, the channels are able to be separated adequately. In an OFDM system, on the other hand, the channels actually overlap. As a result, it is possible to maximize the symbol rate, and thus the throughput, for a given bandwidth. In the image below, we illustrate overlapping sub-carriers in an OFDM system. In this scenario, the channel bandwidth (BW) approaches 1/Rs. Thus, as the number of sub-carriers approaches infinity, OFDM systems allow for nearly double the spectral efficiency.

Note that with an OFDM system, it is still required to have a guard band between each individual channel. However, the effective symbol rate for the combined sub-carriers is greater than if a single carrier were used instead.

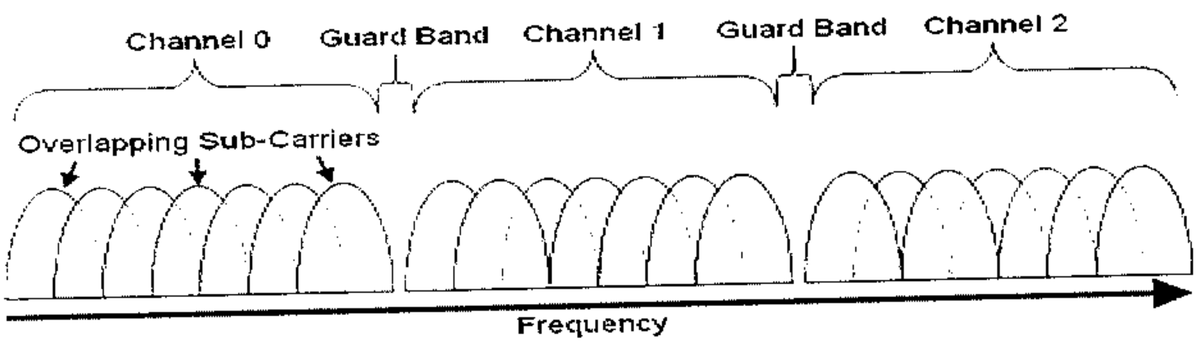

FIG.3.9. FREQUENCY DOMAIN OF OFDM

Note that the effect of using overlapping orthogonal sub-carriers also requires the use of a cyclic prefix to prevent inter symbol interference (ISI). Thus, some of the advantages gained through overlapping sub-carriers are compromised.

3.5.2. REDUCED INTER SYMBOL INTERFERENCE (ISI)

In mono-carrier systems, inter symbol interference is often caused through the multi-path characteristics of a wireless communications channel. Note that when transmitting an electromagnetic wave over a long distance, the signal passes through a variety of physical mediums. As a result, the actual received signal contains the direct path signal overlaid with signal reflections of smaller amplitudes. The diagram below illustrates how, at high symbol rates; reflected signals can interfere with subsequent symbols. In wireless systems, this creates difficulty because the received signal can be slightly distorted. In this scenario, the direct path signal arrives as expected, but slightly attenuated reflections arrive later in time. These reflections create a challenge because they interfere with subsequent symbols transmitted along the direct path. These signal reflections are typically mitigated through a pulse-shaping filter, which attenuates both the starting and ending sections of the symbol period. However, as the figure above illustrates, this problem becomes much more significant at high symbol rates. Because the reflections make up a significant percentage of the symbol period, ISI will also be substantial.

OFDM systems mitigate this problem by utilizing a comparatively long symbol period. In addition, they do this without sacrificing throughput by utilizing multiple sub-carriers per channel. Below, we illustrate the time domain of OFDM symbols.

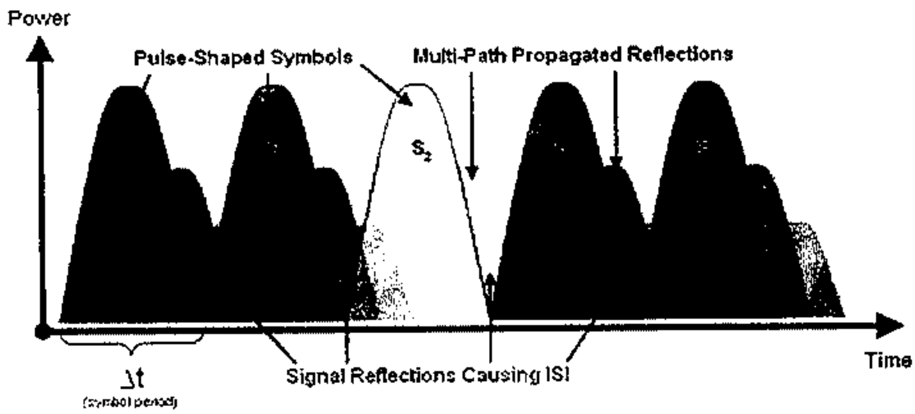

FIG.3.10. ISI AT HIGHER SYMBOL RATES

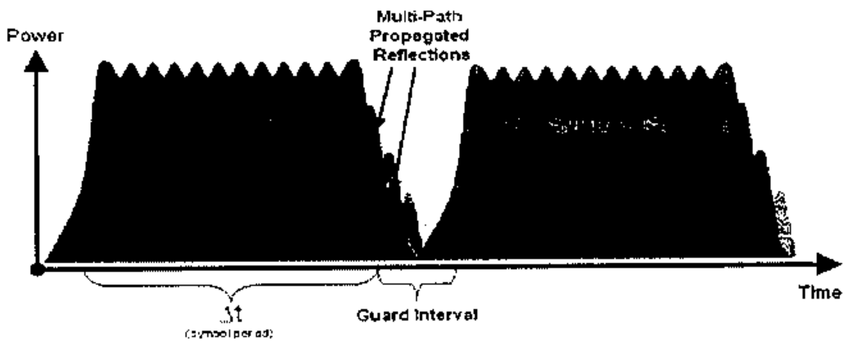

FIG.3.11. REDUCED ISI WITH LOW SYMBOL RATE

Thus, it is possible to simply add a guard interval to remove interference from reflections without significantly decreasing system throughput.

3.6. OFDM APPLICATIONS

- DAB – OFDM forms the basis for the Digital Audio Broadcasting (DAB) standard in the European market.

- ADSL – OFDM forms the basis for the global ADSL (asymmetric digital subscriber line) standard.

- Wireless Local Area Networks – development is ongoing for wireless point-to-point and point-to-multipoint configurations using OFDM technology.

CHAPTER 4

STTCM WITH OFDM

CHAPTER 4

STTCM WITH OFDM

Consider an STTC-OFDM system with K subcarriers, N transmitter antennas and M receiver antennas, signalling through a fading channel. Each STC code word consists of (N K) STC symbols and transmits simultaneously during one OFDM word. Each STC symbol is transmitted at a particular OFDM subcarrier and a particular transmitter antenna. It is assumed that the fading process remains static during each OFDM word; and the fading processes associated with different transmitter-receiver antenna pair are uncorrelated. In this STTC-OFDM scheme, the signals are received from M receiver antennas.

4.1. BLOCK DIAGRAM

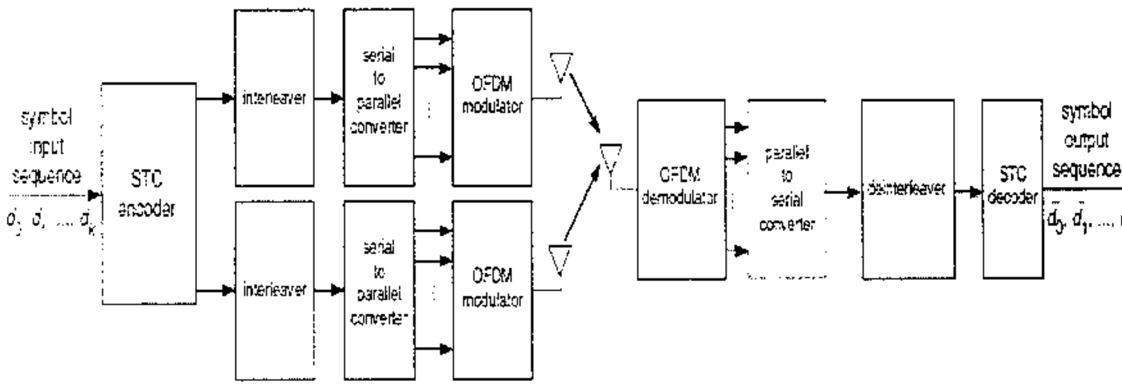

FIG.4.1 BLOCK DIAGRAM OF STTCM WITH OFDM

4.2. DESCRIPTION

After matched filtering and symbol-rate sampling, the discrete Fourier transform (DFT) is applied to the received discrete-time signal to obtain:k = 1, ..., K , where H[k]€ CMxNis the matrix of complex channel responses at the k-th subcarrier ,CN and y [k]C~M are respectively the transmitted signal and the received signal at the k-th subcarrier; z [k]C~M is the ambient noise, which is circularly symmetric complex Gaussian variable with unit Variance. As an example, an STTC-OFDM system with N=2transmitter antennas and M=2 receiver antenna.

At the transmitter, the information source generates the Space-Time Trellis encoder. We will use the improved STTC, which is explained below. The modulation schemes employed are 4-level Phase Shift Keying (QPSK) as well as8-levelphase Shift Keying (8PSK). Different modulation schemes could be employed, such as 16-level Quadrature Amplitude Modulation (16QAM) and level Quadrature Amplitude Modulation (64QAM). Mapping of the bits to symbols was applied and this resulted in different protection classes in higher-order modulation schemes. The output of the Space-Time Trellis encoder was then OFDM modulated with the aid of the Inverse Fast Fourier Transform (IFFT) blocks of Figure and transmitted by the corresponding antenna.

At the receiver the signal of each receive antenna is OFDM demodulated. The demodulated signals of the receiver antennas are then fed to the Space-Time Trellis decoder. The space-time trellis decoder applies the Maximum Likelihood algorithm.

CHAPTER 5

IMPLEMENTATION USING CODE COMPOSER STUDIO

CHAPTER 5

IMPLEMENTATION USING CODE COMPOSER STUDIO

5.1. CODE COMPOSER STUDIO

Code composer studio is an integrated development environment which is used for programming the DSP of Texas instrument. The code composer studio includes the real time operating system called DSP/BIOS. DSP/BIOS is a real time operating system created and offered by Texas Instruments (TI) for use in a wide range of their embedded processors. DSP/BIOS is a component of TI's Code Composer Studio integrated development environment. The DSP/BIOS is a simple operating system for TI DSPs. It can multitask, so you can run different programs simultaneously, provide various debugging, profiling, and logging facilities, and provide APIs for common tasks. There is overhead associated with the DSP/BIOS, so if you don't need it, you probably shouldn't use it. Also, there is a learning curve. You don't need to enable all of its features to use it though, and the core is very small.

Code composer studio is an advanced tool for development and debugging programs for DSPs from Texas instruments. CCS provides an integrated development environment wherein editing source file, executing and debugging program and viewing the graphical output waveforms can all be carried out using multiple windows simultaneously.

The advanced editor permits easy file manipulations and which enables to easily view source, include library files. It automatically tracks file dependencies and edits within the IDE supporting the features such as editing c and assembly source code together, syntax highlighting parenthesis and brace matching, find and replace, quick search and context sensitive help.

CCS has an efficient compiler which saves time by programming in C. It includes integrated code generation tools which supports features like graphically configuring build options background build etc.

The debugger within the IDE which permits to inject/extract data signals and customize and automate testing. It also optimizes code and permits visualization of data.Real time data exchange tool in CCS enables real time analysis. This sets up a real time channel between host and target. It supports 20kb per second bandwidth onTMS320C6000.

5.1.1. FEATURES

Code Composer Studio IDE includes a suite of tools used to develop and debug embedded applications. It includes compilers for each of TI's device families, source code editor, project build environment, debugger, profiler, simulators and many other features. The CCStudio IDE provides a single user interface taking you through each step of the application development flow. Familiar tools and interfaces allow users to get started faster than ever before and add functionality to their application thanks to sophisticated productivity tools [12].

5.1.2. DEBUGGER

CCStudio's integrated debugger has DSP-specific capabilities and advanced breakpoints to simplify development. Conditional or hardware breakpoints are based on full C expressions, local variables or registers [12]. The advanced memory window allows you to inspect each level of memory so that you can debug complex cache coherency issues. CCStudio supports the development of complex systems with multiple processors or cores. Global breakpoints and synchronous operations provide control over multiple processors and cores.

5.1.3. PROFILING

CCStudio's interactive profiler makes it easy to quickly measure code performance and ensure the efficient use of the DSP target's resources during debug and development sessions. The profiler allows developers to easily profile all C/C++ functions in their application for instruction cycles or other events such as cache misses/hits, pipeline stalls and branches. Profile ranges can be used to concentrate efforts on high-usage areas of code during optimization, helping developers produce finely-tuned code [12]. Profiling is available for ranges of assembly, C++ or C code in any combination. To increase productivity, all profiling facilities are available throughout the development cycle.

5.1.4. SCRIPTING

Some tasks such as testing need to run for hours or days without user interaction. To accomplish such a task, the IDE should be able to automate common tasks. CCStudio has a complete scripting environment allowing for the automation of repetitive tasks such as testing and performance benchmarking [12]. A separate scripting console allows you to type commands or to execute scripts within the IDE.

CHAPTER 6

CONCLUSION

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CONCLUSION

This project provides solution to implement a bandwidth efficient modulation technique with high data rate for wireless communication using signal processor. It finds its application in sending and receiving information in an efficient manner.

In this project, we have achieved high data rates using Space Time Trellis Coded Modulation and Orthogonal Frequency Division Multiplexing implemented in digital signal processor using code composer studio. The encoding method used is Convolutional encoding and the decoding method used is Viterbi decoding method. High coding gain and diversity gain are achieved by using STTCM.

Using OFDM, intersymbol interference is much reduced as the method is based on orthogonality. Thus in future to increase usability of the available spectrum the technique of orthogonal frequency division multiple access can be developed. The OFDMA can provide a feasible accessing technique for customers with the service providers able to provide the better method for wireless communication.

APPENDIX

APPENDIX

Space Time Trellis Encoder

```
#include<stdio.h>
void main()
{
 int i,j,n,d[10][10],m[100],r[10][10],x[10][10],z1,z2,z3,z4,w1[10];
 d[10][10]=x[10][10]=r[10][10]=m[100]=0;
//VARIABLES ARE ASSIGNED
 printf("enter the number of input bits:");
 scanf("%d",&n);
 printf("enter the input sequence:");
 for(j=0;j<n;j++)
 {
  scanf("%d",&m[j]);
s }
 j=0;
 for(i=0;i<n/2;i++)//ASSIGN VALUE FOR DELAY ELEMENT
 {
  d[0][i]=m[j];
  d[1][i]=m[j+1];
  j=j+2;
 }
 r[0][0]=0;
 r[1][0]=0;
```

```
j=0;
for(i=1;i<n/2;i++,j++)
{
 r[0][i]=d[0][j];
 r[1][i]=d[1][j];
}
printf("enter the value of the weights:");
for(j=0;j<4;j++)
{
scanf("%d",&w1[10]);
}

for(i=0;i<n/2;i++)//TO ENCODE THE BITS
{
 z1=d[0][i]*0;
 z2=d[1][i]*0;
 z3=r[0][i]*1;
 z4=r[1][i]*2;
 x[0][i]=z1+z2+z3+z4;
}
for(i=0;i<n/2;i++)
{
 z1=d[0][i]*1;
 z2=d[1][i]*2;
 z3=r[0][i]*0;
 z4=r[1][i]*0;
```

```
 x[1][i]=z1+z2+z3+z4;
 }
 printf("the transmitted signal x is\n");
 for(i=0;i<n/2;i++)
  {
printf("%d %d",x[0][i],x[1][i]);
printf("\n");
  }
}
{
 x1[i][j]=0*d[1][0]+0*d[1][1]+1*d[1][0]+2*d[1][1];
 printf("the transmitted signal x1 is %d",x1[10][10]);
 }
 {
 x2[i][j]=1*d[1][0]+2*d[1][1]+0*d[1][0]+0*d[1][1];
 printf("the transmitted signal x2 is %d",x2[10][10]);
  }
```

Space Time Trellis Decoder

```
#include<stdio.h>
#include<math.h>
void main()
{
 int
ps,bm,m[20],bmf,bm1,bm2,bm3,bm4,y[2][10],k,h11,h12,h21,h22,i,n,a0[3],a1[3
],a2[3],a3[3],b0[3],b1[3],b2[3],b3[3],c0[3],c1[3],c2[3],c3[3],d0[3],d1[3],d2[3],d
3[3],enb[100];//VARIABLES ARE ASSIGNED
 for(i=0;i<100;i++)
 enb[i]=0;
 printf("\n enter the no of encoded bits");
 scanf("%d",&n);
 printf("\n enter the encoded bits");
 for(i=0;i<n;i++)
 scanf("%d",&enb[i]);
//TO GET THE TRELLIS
printf("\n enter next state and output for 1 state for the i/p 0 ");
 for(i=0;i<3;i++)
 scanf("%d",&a0[i]);
 printf("\n enter next state and output for 1 state for the i/p 1 ");
 for(i=0;i<3;i++)
 scanf("%d",&a1[i]);
 printf("\n enter next state and output for 2 state for the i/p 0 ");
```

```
for(i=0;i<3;i++)
scanf("%d",&b0[i]);
printf("\n enter next state and output for 2 state for the i/p 1 ");
for(i=0;i<3;i++)
scanf("%d",&b1[i]);
printf("\n enter next state and output for 3 state for the i/p 0 ");
for(i=0;i<3;i++)
scanf("%d",&c0[i]);
printf("\n enter next state and output for 3 state for the i/p 1 ");
for(i=0;i<3;i++)
scanf("%d",&c1[i]);
printf("\n enter next state and output for 4 state for the i/p 0 ");
for(i=0;i<3;i++)
scanf("%d",&d0[i]);
printf("\n enter next state and output for 4 state for the i/p 1 ");
for(i=0;i<3;i++)
scanf("%d",&d1[i]);
ps=1;//PRESENT STATE IS ASSIGNED
k=0;
bmf=0;
h11=1;
h12=2;
h21=2;
h22=1;
for(i=0;i<n/2;i++)//TO CALCULETE PATH MATRIX
{
```

```
 y[0][i]=h11*enb[k]+h12*enb[k+1];
 y[1][i]=h21*enb[k]+h22*enb[k+1];
 k=k+2;
}

for(i=0;i<n;i++)
{
 switch(ps)//TO SWITCH STATE ACCORDING TO PATH MATRIX
 {
bm1=0,bm2=0,bm3=0,bm4=0;
case 1:
            bm1=(y[0][i]-h11*a0[0]-h12*a0[1]+y[1][i]-h21*a0[1]-
h22*a0[2])*(y[0][i]-h11*a0[0]-h12*a0[1]+y[1][i]-h21*a0[1]-h22*a0[2]);
            bm2=(y[0][i]-h11*a1[0]-h12*a1[1]+y[1][i]-h21*a1[1]-
h22*a1[2])*(y[0][i]-h11*a1[0]-h12*a1[1]+y[1][i]-h21*a1[1]-h22*a1[2]);
            bm3=(y[0][i]-h11*a2[0]-h12*a2[1]+y[1][i]-h21*a2[1]-
h22*a2[2])*(y[0][i]-h11*a2[0]-h12*a2[1]+y[1][i]-h21*a2[1]-h22*a2[2]);
            bm4=(y[0][i]-h11*a3[0]-h12*a3[1]+y[1][i]-h21*a3[1]-
h22*a3[2])*(y[0][i]-h11*a3[0]-h12*a3[1]+y[1][i]-h21*a3[1]-h22*a3[2]);
            if(bm1>bm2)
            {
             bm=bm1;
             ps=1;
             m[i]=a0[0];
            }
            else
```

```
{
 bm=bm2;
 ps=2;
 m[i]=a1[0];
}
if(bm>bm3)
bm=bm;
else
{
 bm=bm3;
 ps=3;
 m[i]=a2[0];
}
if(bm>bm4)
bm=bm;
else
{
 bm=bm4;
 ps=4;
 m[i]=a3[0];
}
bmf=bmf+bm*bm;
break;

case 2:
```

```
bm1=(y[0][i]-h11*b0[0]-h12*b0[1]+y[1][i]-h21*b0[1]-h22*b0[2])*(y[0][i]-h11*b0[0]-h12*b0[1]+y[1][i]-h21*b0[1]-h22*b0[2]);
bm2=(y[0][i]-h11*b1[0]-h12*b1[1]+y[1][i]-h21*b1[1]-h22*b1[2])*(y[0][i]-h11*b1[0]-h12*b1[1]+y[1][i]-h21*b1[1]-h22*b1[2]);
bm3=(y[0][i]-h11*b2[0]-h12*b2[1]+y[1][i]-h21*b2[1]-h22*b2[2])*(y[0][i]-h11*b2[0]-h12*b2[1]+y[1][i]-h21*b2[1]-h22*b2[2]);
bm4=(y[0][i]-h11*b3[0]-h12*b3[1]+y[1][i]-h21*b3[1]-h22*b3[2])*(y[0][i]-h11*b3[0]-h12*b3[1]+y[1][i]-h21*b3[1]-h22*b3[2]);
if(bm1>bm2)
{
 bm=bm1;
 ps=1;
 m[i]=b0[0];
}
else
{
 bm=bm2;
 ps=2;
 m[i]=b1[0];
}
if(bm>bm3)
bm=bm;
else
{
 bm=bm3;
 ps=3;
```

```
                    m[i]=b2[0];
                    }
                    if(bm>bm4)
                    bm=bm;
                    else
                    {
                     bm=bm4;
                     ps=4;
                     m[i]=b3[0];
                    }
                    bmf=bmf+bm*bm;
                     break;
        case 3:
                    bm1=(y[0][i]-h11*c0[0]-h12*c0[1]+y[1][i]-h21*c0[1]-
h22*c0[2])*(y[0][i]-h11*c0[0]-h12*c0[1]+y[1][i]-h21*c0[1]-h22*c0[2]);
                    bm2=(y[0][i]-h11*c1[0]-h12*c1[1]+y[1][i]-h21*c1[1]-
h22*c1[2])*(y[0][i]-h11*c1[0]-h12*c1[1]+y[1][i]-h21*c1[1]-h22*c1[2]);
                    bm3=(y[0][i]-h11*c2[0]-h12*c2[1]+y[1][i]-h21*c2[1]-
h22*c2[2])*(y[0][i]-h11*c2[0]-h12*c2[1]+y[1][i]-h21*c2[1]-h22*c2[2]);
                    bm4=(y[0][i]-h11*c3[0]-h12*c3[1]+y[1][i]-h21*c3[1]-
h22*c3[2])*(y[0][i]-h11*c3[0]-h12*c3[1]+y[1][i]-h21*c3[1]-h22*c3[2]);
                    if(bm1>bm2)
                    {
                     bm=bm1;
                     ps=1;
                     m[i]=c0[0];
```

```
            }
            else
            {
             bm=bm2;
             ps=2;
             m[i]=c1[0];
            }
            if(bm>bm3)
            bm=bm;
            else
            {
             bm=bm3;
             ps=3;
             m[i]=c2[0];
            }
            if(bm>bm4)
            bm=bm;
            else
            {
             bm=bm4;
             ps=4;
             m[i]=c3[0];
            }
            bmf=bmf+bm*bm;
            break;
case 4:
```

```
bm1=(y[0][i]-h11*d0[0]-h12*d0[1]+y[1][i]-h21*d0[1]-
h22*d0[2])*(y[0][i]-h11*d0[0]-h12*d0[1]+y[1][i]-h21*d0[1]-h22*d0[2]);
bm2=(y[0][i]-h11*d1[0]-h12*d1[1]+y[1][i]-h21*d1[1]-
h22*d1[2])*(y[0][i]-h11*d1[0]-h12*d1[1]+y[1][i]-h21*d1[1]-h22*d1[2]);
bm3=(y[0][i]-h11*d2[0]-h12*d2[1]+y[1][i]-h21*d2[1]-
h22*d2[2])*(y[0][i]-h11*d2[0]-h12*d2[1]+y[1][i]-h21*d2[1]-h22*d2[2]);
bm4=(y[0][i]-h11*d3[0]-h12*d3[1]+y[1][i]-h21*d3[1]-
h22*d3[2])*(y[0][i]-h11*d3[0]-h12*d3[1]+y[1][i]-h21*d3[1]-h22*d3[2]);
if(bm1>bm2)
{
 bm=bm1;
 ps=1;
 m[i]=d0[0];
}
else
{
 bm=bm2;
 ps=2;
 m[i]=d1[0];
}
if(bm>bm3)
bm=bm;
else
{
 bm=bm3;
 ps=3;
```

```
                m[i]=d2[0];
               }
               if(bm>bm4)
               bm=bm;
               else
               {
                bm=bm4;
                ps=4;
                m[i]=d3[0];
               }
               bmf=bmf+bm*bm;
               break;

  }

 }
 printf("decoded message bits are\n");
//TO DISPLAY DECODED MESSAGE
 for(i=0;i<n;i++)
 printf("%d",m[i]);
}
```

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REFERENCES

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